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Full Length Article



Assessment of reinforced concrete building damages following the Kahramanmaraş earthquakes in Malatya, Turkey (February 6, 2023)

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ABSTRACT

Earthquakes of magnitude $M_w = 7.7$ and $M_w = 7.6$ hit the city of Kahramanmaraş (Turkey) on 6 February 2023. These earthquakes caused serious damage in 11 provinces in Turkey resulting in over 50,000 deaths and huge economic losses with the collapse of thousands of buildings. Two consecutive devastating earthquakes have severely damaged the reinforced concrete building stock located in Malatya. There are many reasons reinforced concrete structures suffer damage under the influence of seismic loads. These reasons can be listed as material and section properties that do not comply with earthquake codes, workmanship defects, ground parameters that are not considered and design errors, as seen in field investigations after earthquakes in Turkey in the past. In this research, a field study was conducted on reinforced concrete buildings damaged after the earthquakes in Malatya province. The causes of structural damages in reinforced concrete buildings between 6–26 years of age were assessed in terms of design and material defects. The structural damages were mainly caused due to insufficient stirrups in structural members, short column, strong beam–weak column, failures of infill walls, soft story type collapse, poor concrete quality, and reinforcement corrosion. In addition to the field investigation, the spectrum relationships created using raw acceleration data obtained from DEMP (Disaster and Emergency Management Presidency) stations in Malatya province were compared with the design response spectra.

1. Introduction

Earthquakes turn into disasters due to structures that have not received engineering service, causing economic, social, and psychological negativities in society as well as loss of life. In Anatolia, which is in the active seismic zone, the loss of life and property in the major earthquakes that have occurred in recent years has raised many questions about the status of the existing structures. Determining the current damage status of the structures after the earthquakes and making the decision to reuse, repair/strengthening or demolish the structure is important in terms of both economic and life safety issues. Many technical and scientific reports have been written for collapsed or heavily damaged structures, and the status of the existing building stock has been evaluated.

After numerous catastrophic earthquakes (Gölcük earthquake $M_w = 7.6$ (1999), Gujarat earthquake $M_w = 7.6$ (2001), Christchurch earthquake $M_w = 6.2$ (2011), Van earthquakes Mw 7.1 (2011), Emilia earthquake M_w 6.1 (2012), Sabah earthquake $M_w = 6.0$ (2015), Elazığ-Sivrice earthquake $M_w = 6.8$ (2020), İzmir earthquake $M_w = 6.9$ (2020)), the damages to reinforced concrete structures and the causes of their occurrence have been the subject of study by researchers [1–10]. The losses of life for the Gölcük (1999), Van (2011), Elazığ-Sivrice (2020), and İzmir (2020) earthquakes defined within the scope of the manuscript are 18,373; 13,572; 185, 604; 41; and 119, respectively. The number of buildings destroyed/damaged in these earthquakes was determined as 133,683; 339,000; 2, 262; 76; and 523,respectively.

For example, in the report [11] published by the Chamber of Civil Engineers after the Izmir Earthquake on October 30, 2020, it was stated that collapses occurred at early drift ratios due to insufficient confinement reinforcement details, insufficient lap splice lengths and low concrete compressive strength in structures built before the 1998 Turkish Earthquake Code. In addition, in the observations conducted in the disaster area after the Elâzığ-Sivrice earthquake that occurred on January 24, 2020, it was once again determined that insufficient reinforcement bar details and low-quality concrete were found in the columns of the heavily damaged reinforced concrete structures. Considering the available earthquake reports, the damages caused by seismic activity in reinforced concrete structures can be analyzed under

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Table 1
Earthquakes on the East Fault Zone (EAFZ).

Year	Location	Magnitude (M_w)
1945	Ceyhan, Adana	6.1
1949	Karlıova	6.7
1951	İskenderun	5.8
1952	İmamoğlu, Adana	5.6
1964	Malatya	6.0
1966	Karlıova	5.6
1971	Bingöl	6.8
1979	Kozan, Adana	5.5
1986	Gölbaşı, Sürgü	5.6
1998	Ceyhan, Adana	6.2
2003	Bingöl	6.3
2010	Karakoçan, Elazığ	6.0
2012	Sivrice, Elazığ	5.5
2020	Sivrice, Elazığ	6.8
2023	Kozan, Adana	5.6

two main topics: design defects and material/workmanship deficiencies.

On 06.02.2023, two earthquakes of $M_w = 7.7$ and $M_w = 7.6$ with epicenters in Pazarcık (Kahramanmaraş) and Elbistan (Kahramanmaraş) occurred at 04:17 and 13:24 (local time), respectively. These earthquakes were also felt in many regions of Anatolia and caused devastating consequences in Kahramanmaras, Hatay, Gaziantep, Kilis, Osmaniye, Adana, Şanlıurfa, Adıyaman, Diyarbakır and Malatya provinces.

The number of heavily damaged/collapsed reinforced concrete buildings in Malatya province as a result of earthquakes is 32,195. There are a total of 71,549 houses and 14,397 commercial areas in these buildings. The number of people who died in the earthquakes was recorded as 1,246. It is thought that the total damage caused by the earthquakes to the Malatya economy is approximately 1.5 million dollars. No definitive information can be found about structures with masonry or steel building systems.

In this study, the reinforced concrete structures damaged after the Kahramanmaraş Pazarcık ($M_w = 7.7$) and Elbistan ($M_w = 7.6$) earthquakes in the central districts of Malatya (Center, Battalgazi and Yeşilyurt) and the causes of damage in Malatya were evaluated in terms of design defects and material/workmanship deficiencies.

2. Seismicity and seismotectonic of the region

Turkey has been under the influence of active fault zones for centuries due to its geological location. In eastern Turkey, the Arabian Plate is moving towards the Anatolian Plate in the NW direction at a rate of 18 mm per year [12,13]. This movement of the Anatolian Plate occurs along two major strike-slip fault systems: the North Anatolian Fault Zone (NAFZ) and the left-lateral strike-slip East Anatolian Fault Zone (EAFZ). Table 1 lists the major earthquakes that occurred on the East Anatolian Fault Zone (EAFZ) in the last century.

The recent $M_w = 7.7$ Pazarcık earthquake struck the Narlı Segment at the northern end of the left-lateral strike-slip Ölü Deniz Fault Zone, while the $M_w = 7.6$ Elbistan earthquake struck the Çardak Fault, a branch of the East Anatolian Fault. After these devastating earthquakes, numerous aftershocks occurred in the region (Fig. 1).

3. The process of strong-ground motions data

Raw acceleration data obtained from AFAD stations in Malatya province were analyzed during the Kahramanmaraş earthquakes on February 6, 2023. Table 2 provides detailed information on the AFAD stations that were recorded during both earthquakes. Additionally, Table 2 gives the values of average shear wave velocity of the (V_s30) used to distinguish soil categories in most of the international seismic codes (e.g. EUROCODE 8 [21]). The classifiable of stations 4406, 4409, 4405, and 4412, which are considered within the scope of the study, are defined as A, A, C, and C respectively according to EUROCODE 8. Fig. 2 shows a map of the field investigation region and record station

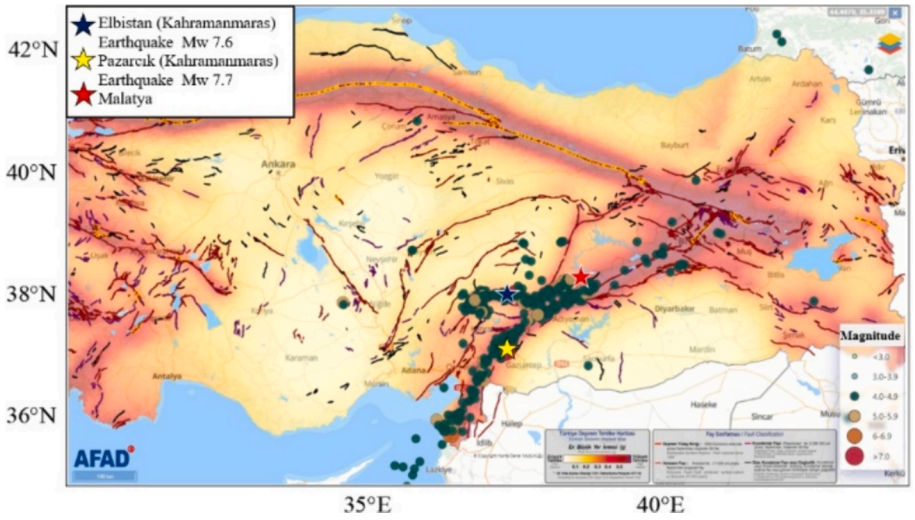


Fig. 1. 06.02.2023 Pazarcık (Kahramanmaras) $M_w = 7.7$ and Elbistan (Kahramanmaras) $M_w = 7.6$ earthquakes and aftershock activity (06.02.2023–06.03.2023) [14].

Table 2
Information of AFAD stations in Malatya province.

Station code	Location	Altitude (m)	Latitude	Longitude	V_s30 (m/s)	Distance from the epicenter (km)	
						Pazarcık ($M_w = 7.7$)	Elbistan ($M_w = 7.6$)
4406	Malatya-Akçadağ	1050	38.3438	37.9737	815	143.07	70.17
4409	Malatya-Darende	1055	38.5606	37.4907	830	146,86	56.86
4405	Malatya-Hekimhan	1147	38.8107	37.9396	579	186.63	100.81
4412	Malatya-Yazıhan	820	38.5968	38.1838	360	176.60	99.89

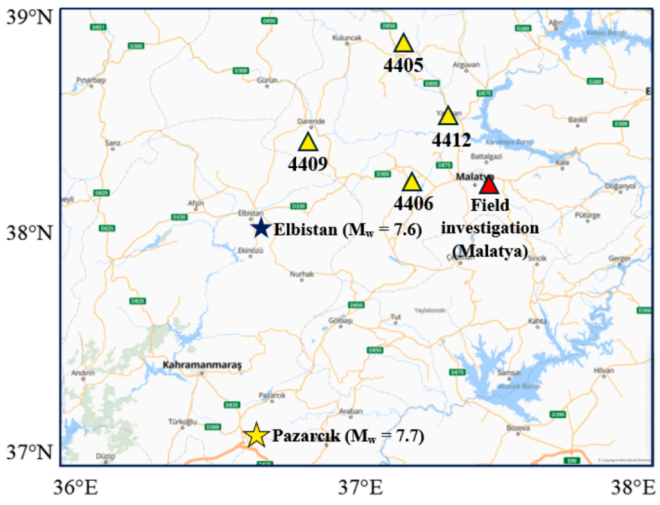


Fig. 2. Epicenters, stations, and field investigation areas depicted on the map.

locations. Acceleration-time, velocity–time, displacement–time, and arias intensity (5 %, 95 %) effective durations based on the arias density relations were determined for the Pazarcık ($M_w = 7.7$) and Elbistan ($M_w = 7.6$) earthquakes.

Raw ground motion data obtained from Akçadağ (4406), Darende (4409), Hekimhan (4405), and Yazıhan (4412) stations were processed as shown in Fig. 3, Fig. 4, Fig. 5, and Fig. 6, respectively. Effective components of ground motion records were used in the processing of earthquake data. The determined characteristic features of ground motion records according to processed data are summarized in Table 3 for Pazarcık ($M_w = 7.7$) earthquake and in Table 4 for Elbistan ($M_w = 7.6$) earthquake.

When the earthquake characteristics given in Table 3 and Table 4 are examined, it is understood that the Elbistan ($M_w = 7.6$) earthquake that occurred on February 6, 2023, at 13.24 was more destructive for Malatya province. As can be seen from Table 2, the epicenter of the Elbistan ($M_w = 7.6$) earthquake is closer to Malatya than the epicenter of the Pazarcık ($M_w = 7.7$) earthquake. The highest peak ground acceleration (PGA) value was recorded at Akçadağ station (4406) for the Elbistan ($M_w = 7.6$) earthquake, and the effective duration of this ground motion was calculated as 17.43 s.

The relationship indicating the behavior of a single degree of freedom system subjected to strong ground motion depending on the free vibration period is defined as the earthquake spectrum. Response spectra curves for 5 % damping ratio were created for Malatya province through raw acceleration data obtained from AFAD stations indicated on the map in Fig. 2. In this context, the obtained spectrum curves were associated with the design spectra in the earthquake regulations, including the construction years of the observed buildings (Fig. 7).

In the Elbistan ($M_w = 7.6$) earthquake, it was observed that the spectrum generated with the data obtained from Akçadağ Station exceeded the design spectra for structures with a period between 0–0.5 sec. In Fig. 7 (a), it is seen that all the response spectra for the Elbistan earthquake do not exceed the response spectra given in the TEC [15] and TBEC [16] earthquake codes for structures with a natural period of vibration between 0–2 s. For the Pazarcık earthquake ($M_w = 7.7$), it was observed that the design spectrum was exceeded only for buildings designed according to ZA soil class (Fig. 7 (b)). It is known that in the regions where field study was carried out, there was no region with solid rock ground with ZA soil class. Fig. 7 (c) shows the average spectrum curves of earthquakes. In addition, when the spectra obtained from all stations were geometrically averaged, it was determined that these data did not exceed the design spectrum curves.

The response spectra created using acceleration data obtained from stations in Malatya province during the Kahramanmaraş earthquakes were generally below the design spectra in the 2007 and 2018 Earthquakes codes. For this reason, material deficiencies or workmanship defects have come to the fore for heavily damaged or totally collapsed buildings.

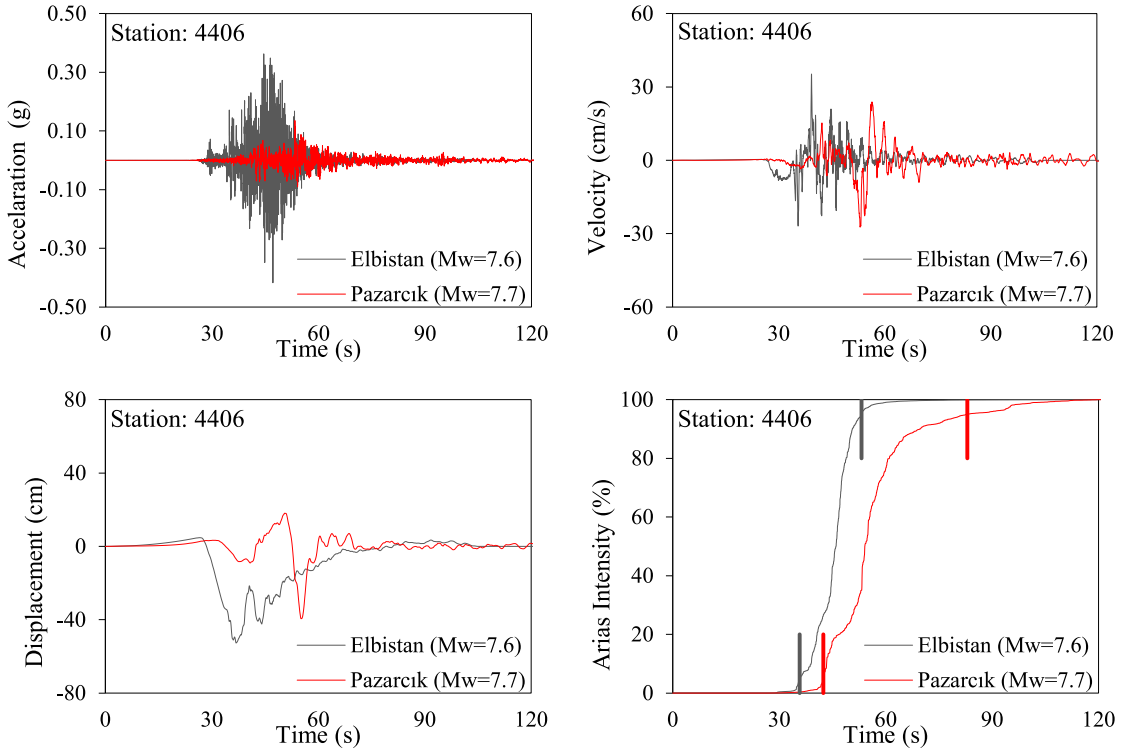


Fig. 3. Processed of raw ground motion records obtained from AFAD-4406 (Akçadağ) seismic station.

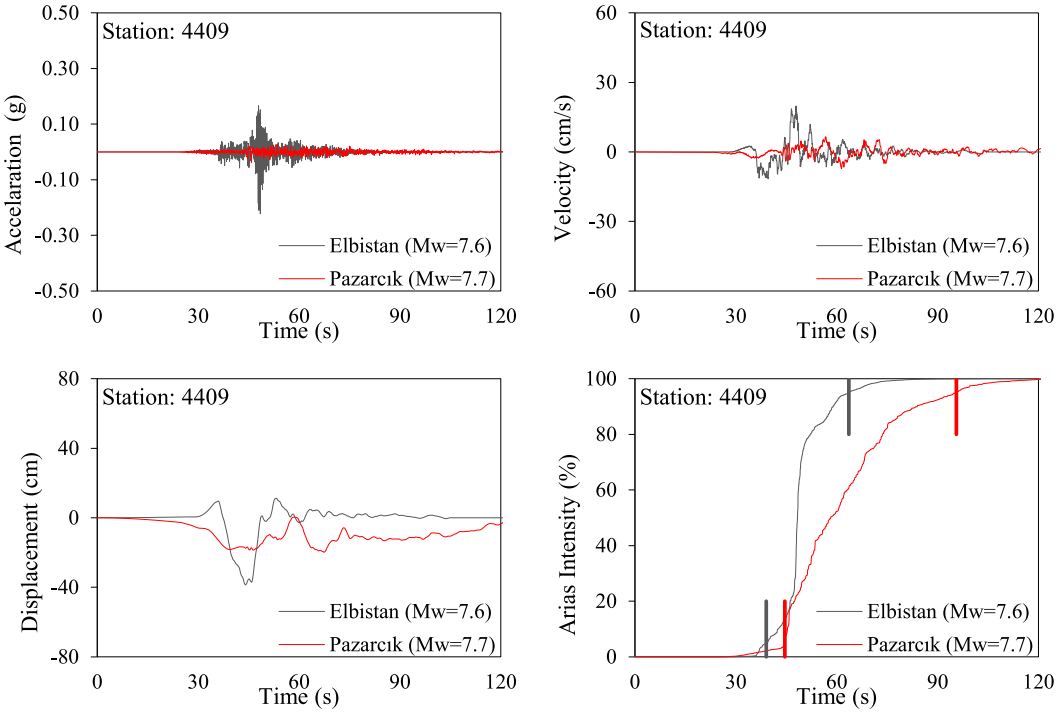


Fig. 4. Processed of raw ground motion records obtained from AFAD-4409 (Darende) seismic station.

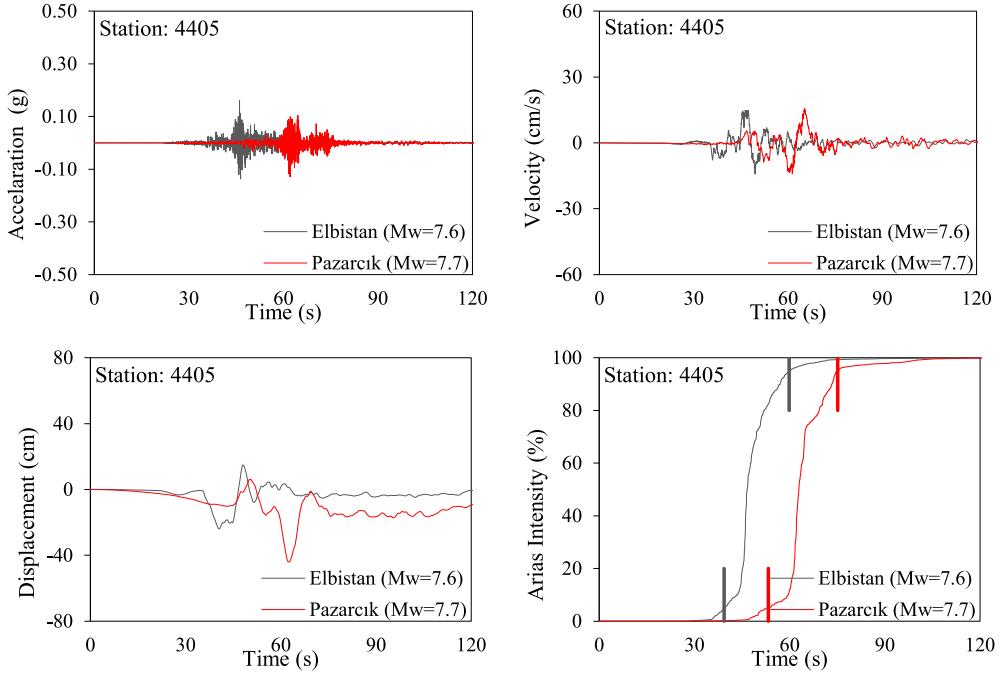


Fig. 5. Processed of raw ground motion records obtained from AFAD-4405 (Hekimhan) seismic station.

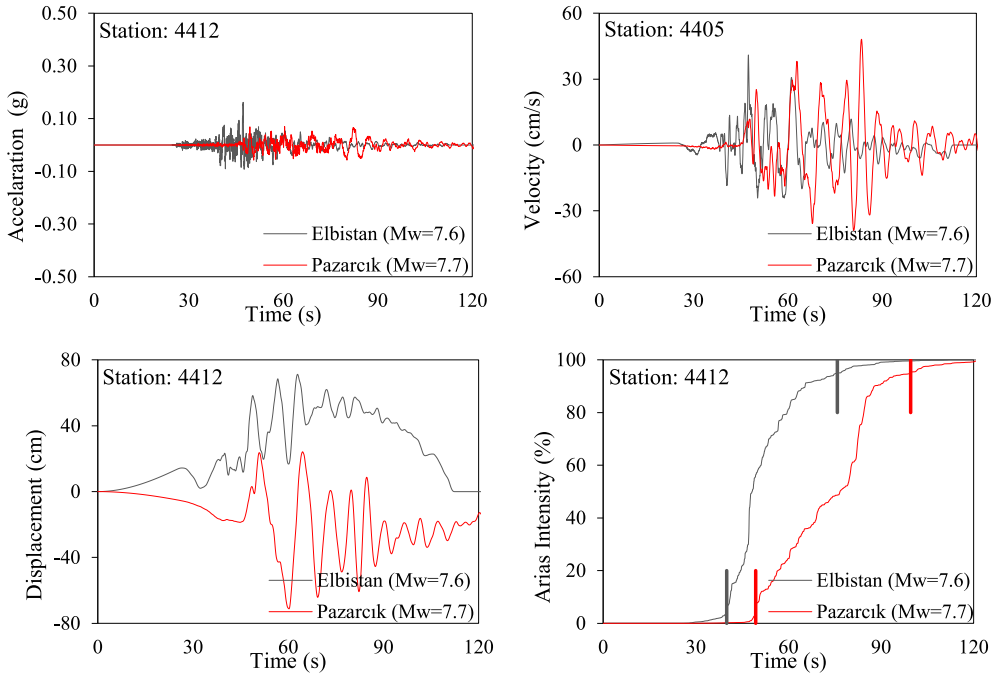


Fig. 6. Processed of raw ground motion records obtained from AFAD-4412 (Yazıhan) seismic station.

Table 3
Characteristics of Pazarcık ($M_w = 7.7$) earthquake.

EffectiveComponent	Location of station	PGA (g)	PGV (cm/s)	PGD (cm)	EffectiveDuration (s)
E-W	Malatya-Akçadağ	0.137	27.33	39.43	40.58
N-S	Malatya-Darende	0.038	7.21	19.79	51.01
E-W	Malatya-Hekimhan	0.128	15.67	43.95	21.86
E-W	Malatya-Yazıhan	0.070	47.46	44.62	50.19

Table 4
Characteristics of Elbistan ($M_w = 7.6$) earthquake.

EffectiveComponent	Location of station	PGA (g)	PGV (cm/s)	PGD (cm)	EffectiveDuration (s)
N-S	Malatya-Akçadağ	0.476	21.33	20.10	17.43
N-S	Malatya-Darende	0.222	19.79	38.59	24.56
E-W	Malatya-Hekimhan	0.161	14.88	23.91	20.49
N-S	Malatya-Yazıhan	0.162	38.82	28.37	35.84

4. Field investigation

Reliable and rapid damage assessment studies for reinforced concrete structures are extremely important in terms of revealing the current building stock status of the region where seismic activity is experienced. Considering the active risk status of the earthquake zone in the evaluations to be carried out, it is recommended to obtain the parameters to be examined from structural elements in terms of safety and time savings. The post-earthquake damage of reinforced concrete structures is generally divided into two main categories: material performance conditions and design defects of structural elements.

In order to evaluate the effects of the earthquakes on the reinforced concrete building stock, 50 heavily damaged/collapsed reinforced concrete building were randomly selected in Battalgazi and Yesilyurt districts of Malatya province. The damage occurrences observed in the assessed structures are generally due to the reasons listed below.

- Inadequate concrete quality and thus reinforcement corrosion.
- Smooth reinforcement and inadequate lap splice length.
- Inadequate confinement reinforcement.
- Short column effect.
- Soft/weak story.
- Principle of strong beam-weak column.
- Infill wall damage.

4.1. Material deficiency

The limits of the compressive strength of concrete to be utilized in reinforced concrete structures have been specified in the codes. For example, in TEC [17], the minimum concrete compressive strength for the first and second earthquake zones is presented as 18 MPa, while this value is limited to 14 MPa for other earthquake zones. With the spread of ready-mixed concrete production in the construction industry, this value was increased to a minimum value of 16 MPa in TEC [18], 20 MPa in TEC [15] and 25 MPa in TBEC [16].

In addition to the limit values specified for concrete compressive strength, a few requirements are presented in technical specifications and codes for concrete production, concrete pouring operations, and post-operations. During the field investigation, segregation, aggregation

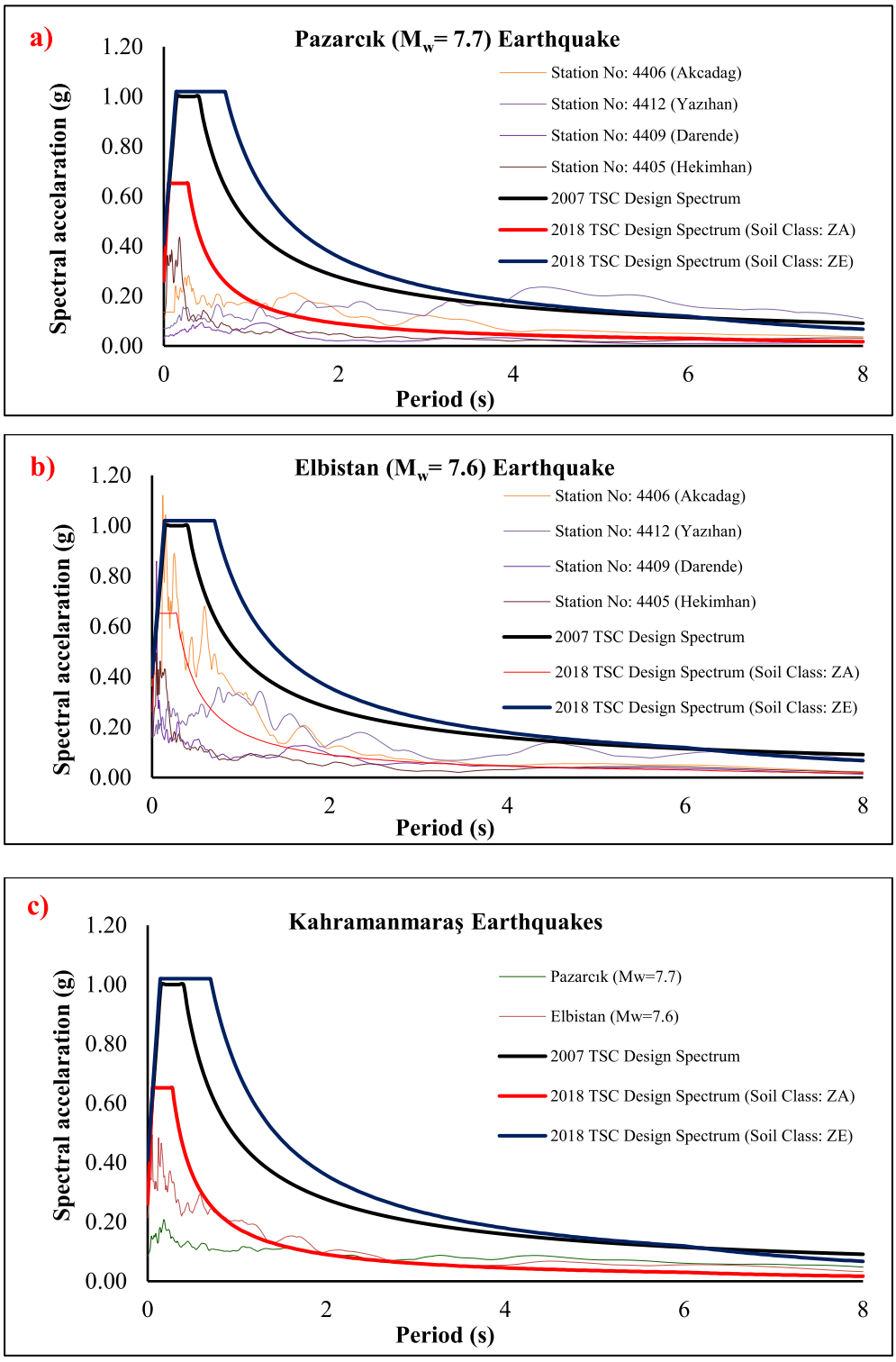


Fig. 7. Comparison of acceleration response spectra with design spectra for the stations in Malatya. a). Pazarcık (M_w = 7.7) Earthquake, b). Elbistan (M_w = 7.6) Earthquake, c). Geometric average spectra.



Fig. 8. A) segregation in columns, b) non – granulometry aggregate c) wood foreign material.

settlement problems as a result of the use of not compliant with standards concrete, as well as the usage of foreign matter in the concrete were detected (Fig. 8). All defects caused by the material significantly reduce the lateral rigidity of the structure. For this reason, the eigen periods of the structures increase in the acceleration response spectra and more earthquake loads affect the structures.

In cases where the target concrete compressive strength is insufficient at the design stage, due to the higher permeability the concrete leaves the reinforcement bar vulnerable to corrosion. As a result of corrosion, it was determined that the cross-sectional area of the reinforcement bar significantly reduced, and the concrete cover spalling due to corrosion (Fig. 9). In addition, it has been observed that smooth reinforcement bar is used in many structures. This situation causes serious loss of bond between concrete and reinforcement bars in reinforced concrete elements (Fig. 10).

4.2. *Design- workmanship defects*

Although there are clear provisions such as the use of ribbed reinforcement, minimum concrete compressive strength, 135° bending of stirrup hooks, tightening of stirrups in column-beam joints, appropriate lengths of lap splices, the strong column-weak beam principle, and consideration of irregularities that are required by the current earthquake regulations of Turkey, many of these basic elements are not provided in 20–25 years old buildings.

4.2.1. *Inadequate reinforcement details and construction defects*

Stirrups in concrete structures are effective both in providing adequate ductility and in resisting the increasing shear forces under the effect of seismic loads. Especially in areas such as column beam joints, which are critical in terms of shear force effects, adequate stirrup is of great importance. In addition to the inadequate use of stirrups in the end zones of the columns during the investigations, the hook fabrication, which should be 135°, was executed as 90°. Shear damages were detected in reinforced concrete columns with missing or improperly implemented confinement reinforcement bars as shown in Fig. 11. The axial load carrying capacity of reinforced concrete structural elements without adequate confinement effect decreases, and the buckling length of the reinforcement bar increases. There are numerical and analytical studies in the literature on the strengthening of reinforced concrete columns damaged due to axial loads with innovative composite materials [23].



Fig. 9. Corroded reinforcement bars.



Fig. 10. Smooth reinforcement bars.



Fig. 11. Shear damage in columns.



Fig. 12. Inadequate transverse reinforcement.

As shown in Fig. 12, longitudinal reinforcement bar buckling occurred in reinforced concrete columns in case of insufficient confinement reinforcement bar. Longitudinal reinforcing bars are left free at the ends of the columns, and insufficient lap lengths cause bond problems in the columns and cause column damage (Fig. 13). It has been shown in the literature that the use of polypropylene fibers in reinforced concrete members with insufficient reinforcement bond length improves the collapse behavior [24]. Due to the bending of the hooks in the stirrups at 90 degrees during manufacturing, the confinement effect in reinforced concrete columns is insufficient, and damage may occur (Fig. 14).

In the shear wall shown in Fig. 15, it is observed that there are cracks covering the surface and crushing in the concrete cover. In Table 5, the definitions of short reinforced concrete walls in various earthquake codes are given. According to the definitions of short shear walls in the codes, since the shear wall presented in Fig. 15 is a short shear wall, the shear force can be as influential as the bending moment. Reinforced concrete columns that have structural deficiencies due to various reasons can be strengthened with innovative composite materials such as CFRP (Carbon Fiber Reinforced Polymer) or TRM (Textile Reinforced Mortar).

From the damage seen in Fig. 16, it is understood that the reinforcement bar detail in the tension region of the reinforced concrete beam is insufficient, and the cantilever element is dimensioned incorrectly.

4.2.2. Soft-story effect

The usage of the ground floors of reinforced concrete structures for commercial purposes is a common occurrence in city centres. The internal reinforced concrete frames are created without infill walls, and the floor heights of the structure to be constructed are greater than the other floors. Vertical irregularities in such buildings cause a sudden decrease in stiffness under the influence of earthquakes, seriously damaging the reinforced concrete structure (Fig. 17).

As it is known, earthquake damages caused by soft story effects are quite common. If soft story formation cannot be prevented during the architectural design due to various reasons (commercial etc), it is extremely important to take the precautions listed below.

1) The cross-sectional area of the columns on the ground floor can be increased.
2) The shear wall ratio in the structure can be increased or new shear wall can be added.
3) In floors with soft story irregularities, all reinforced concrete columns can be confined with stirrups along the length.

4.2.3. Joint reinforcement deficiencies and strong beam-weak column mechanism

According to capacity design principles, it is expected that hinging will first take place at the beam ends before becoming hinged at the column ends under the influence of earthquake loads.

Therefore, it is stipulated in the TBEC [15] that the columns be 20 % stronger than the beams. Tensile and compressive damages occur in the end regions of the column element because of reversible seismic stresses operating on reinforced concrete frame systems. Fig. 18 shows the inadequate densification in the column – beam joint area. In addition to this situation, it is evident from the damage type in the figure that the condition of columns to be 20 % stronger than beams is not met, on the contrary, the beam capacity is designed much higher than the column capacity. Fig. 19 (a) demonstrates a reinforced concrete column with crushed concrete and buckled reinforcement at the end of the column. In Fig. 19 (b), it is seen that the beams are designed to be stronger than the columns, and thus pancake collapse occurs.

4.2.4. Short column effect

As the effective height of reinforced concrete columns decreases,

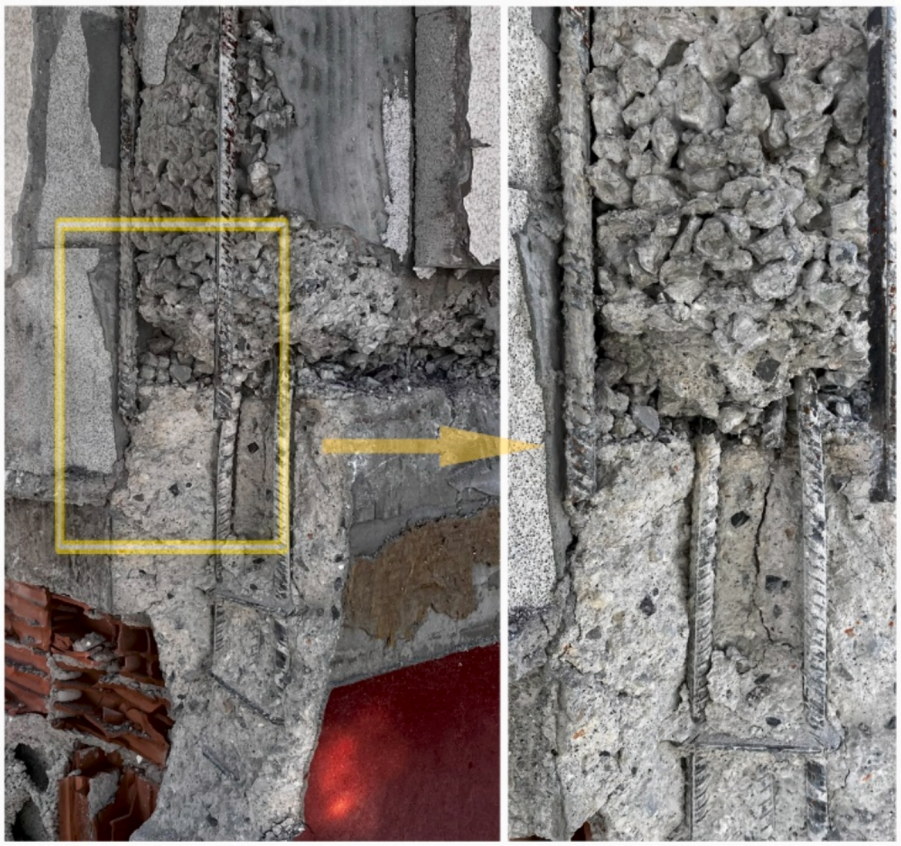


Fig. 13. Unengaged longitudinal bar.



Fig. 14. Stirrup detail 90-degree hook bends.



Fig. 15. Shear damage and reinforcement buckling.

Table 5
Shear wall definitions for earthquake code.

Design Code	Short Shear Wall Definition
FEMA – 356 [19]	height/width < 1,5
ACI – 318 [20]	height/width < 1,5
EUROCODE 8 [21]	height/width < 2
IBC 2000 [22]	height/width < 1,5

stiffness increases. More earthquake load acts on the reinforced concrete column with increasing lateral stiffness. The short column effect may occur in reinforced concrete structures due to various designs. Shear damage may occur in cases where appropriate stirrup densification is not performed according to the short column design (Fig. 20).

If the formation of short columns cannot be prevented due to architectural reasons, reinforcement can be made after the structure is built. Strengthening efforts to prevent sudden brittle failures of short columns have been successful [25,26].

4.2.5. *Infill wall damages*

Infill wall damages are frequently seen in field investigation of reinforced concrete buildings. It is clearly understood from Fig. 21 that the infill walls play a role in transmitting the loads, such as equivalent pressure bar in both directions to the reinforced concrete column-beam nodes carrying the bearing conditions. Under earthquake loads, in-plane, and out-of-plane diagonal X-shaped damages (cracks, collapses) that occur as a result of the movement at the reinforced concrete frame,



Fig. 16. Cantilevered reinforced concrete beam damage.



Fig. 17. Failures and damages of reinforced concrete buildings due to the soft story irregularities.

beam, and column interfaces to which the infill walls are connected significantly reduce or eliminate the contribution of the infill walls to the stiffness of the structure (Fig. 21). There are many studies in the literature in which infill walls are strengthened by various methods [27].

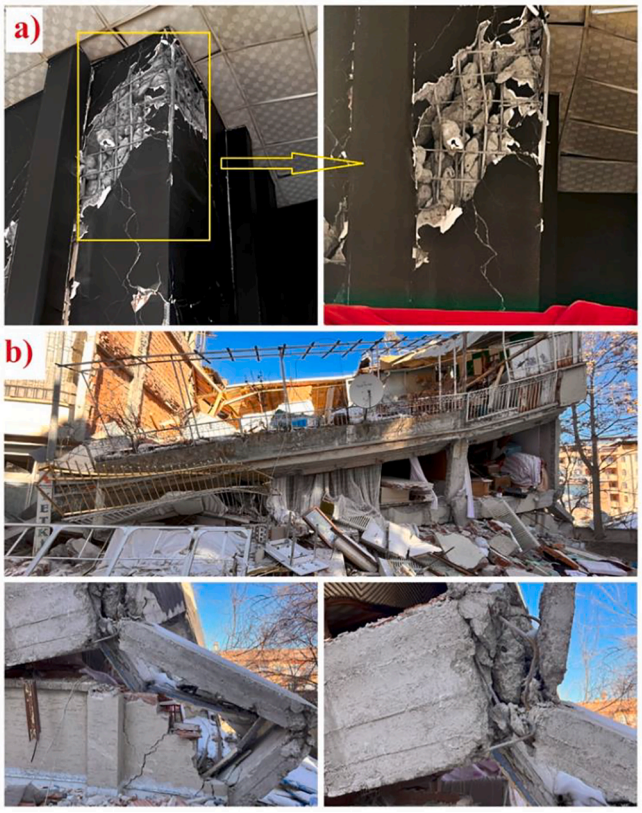


Fig. 19. Strong beam-weak column mechanism.



Fig. 18. Inadequate reinforcement details at joints.

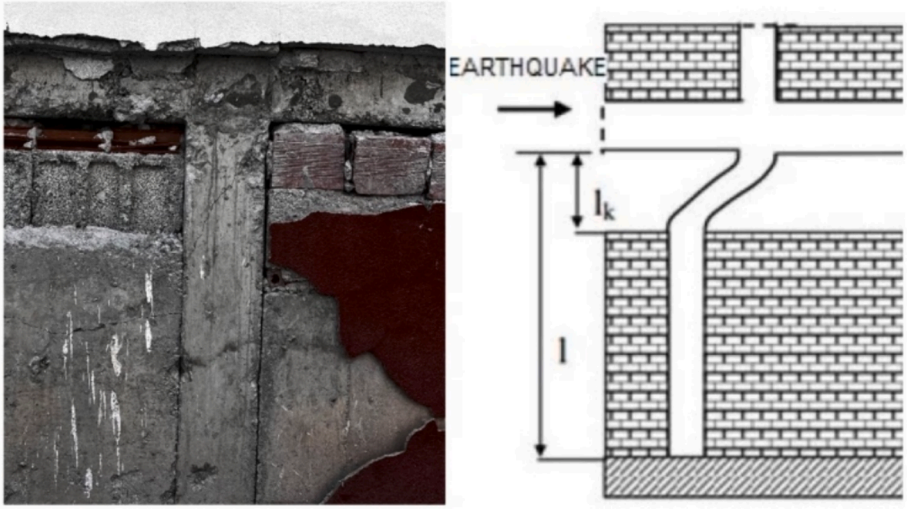


Fig. 20. Short column and shear crack.

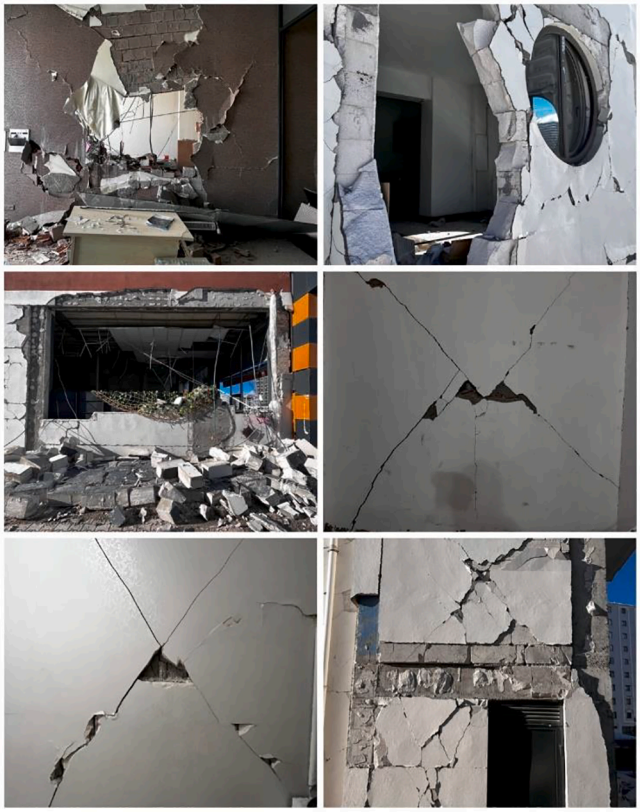


Fig. 21. Shear cracks and damages in infill walls.

4.3. Collapsed RC buildings

The distances of the collapsed RC buildings presented in Fig. 22 to the earthquake epicenters and seismic stations are shown in Table 6.

In this section, a visual comparison of the total collapsed RC buildings with their pre-earthquake condition is presented. In Fig. 22, totally collapsed buildings are shown in the right column. The existence of well-performed structures around the collapsed buildings in Fig. 22 also attracted the attention of the authors during the field study. Since these structures were located very close to the collapsed buildings, it was thought that they were built on the same soil class. For this reason, it was not considered that one of the causes of collapse could be soil parameters (soil amplification phenomena etc.). The collapsed and well-performed buildings were built at the same time, subject to the same past earthquake codes. As a result of all these evaluations, it was concluded that inadequate material quality (poor concrete quality, the use of mostly smooth reinforcement, and inappropriate utilization of stirrups), workmanship defects and lack of inspection were the major causes of collapse.

4.4. Damage types and structural deficiencies

Within the scope of the field investigation, observational inspections were conducted on a total of 50 RC buildings that were severely damaged or collapsed. It was determined that of the RC buildings considered were constructed between 36 % 1987–1997, 34 % between 1997–2007 and 30 % between 2007–2017. The distribution percentages of damage types and structural deficiencies detected in the buildings are presented in the graphs given in Fig. 23 and Fig. 24, respectively.

In Fig. 23, it is observed that the most common type of damage in the investigated RC buildings is caused by the infill wall. In addition, buckling of longitudinal reinforcing bars under axial loads was observed in many of the investigated buildings due to insufficient stirrups reinforcement. It was determined that the most important structural deficiencies in the old buildings examined were low concrete quality and inadequate reinforcement bars (Fig. 24).

5. Conclusion and recommendations

- It is noted that the acceleration response spectra produced by taking into consideration of the acceleration records for the Pazarcık (M_w = 7.7) and Elbistan (M_w = 7.6) earthquakes obtained from the stations in the province of Malatya are below the design spectrum curves according to TEC [15] and TBEC [16].
- The performance levels of the RC buildings constructed according to the seismic codes should remain at the level of immediate occupancy/life safety, depending on the intended purpose of the building. Contrary to this situation, the damaged/collapsed buildings identified in the field investigation indicate that they are not suitable for the relevant seismic codes in terms of design and/or material-workmanship.
- It was observed that the most important defect in the reinforced concrete structures was the inadequate using of stirrups. It was unclear to determine if this was a result of unsuitable design or



Fig. 22. Collapsed RC building: (a, c, e) before and (b, d, f) after the earthquakes.

Table 6
Distances of collapsed RC buildings to the earthquake epicenter and seismic stations.

Collapsed Buildings	Seismic station				Earthquake epicenters	
	4405	4406	4409	4412	Pazarcık	Elbistan
A	76	35	101	38	234	130
C	83	53	122	46	257	172
E	66	32	105	28	164	165

*Units in km.

workmanship because the static projects of the relevant structures were inaccessible.

- In addition, other deficiencies can be listed as inadequate material-mechanical properties of concrete, reinforcement corrosion, use of smooth reinforcement, dimensioning defects of building elements, and insufficient column-beam reinforcement details.
- To prevent reinforcement corrosion, the use of corrosion-resistant composite reinforcement in RC structures to be built in regions exposed to negative environmental effects may be recommended in the seismic codes. Considering these damage conditions, the method to be preferred in strengthening the reinforced concrete structure

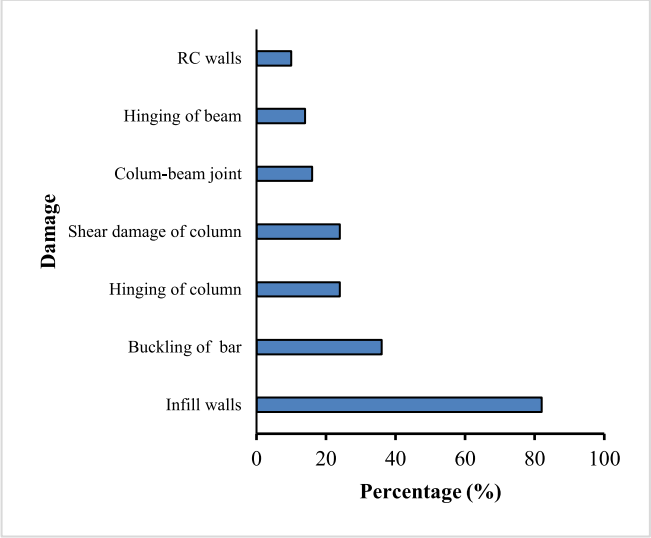


Fig. 23. Percentage of damage types of RC buildings.

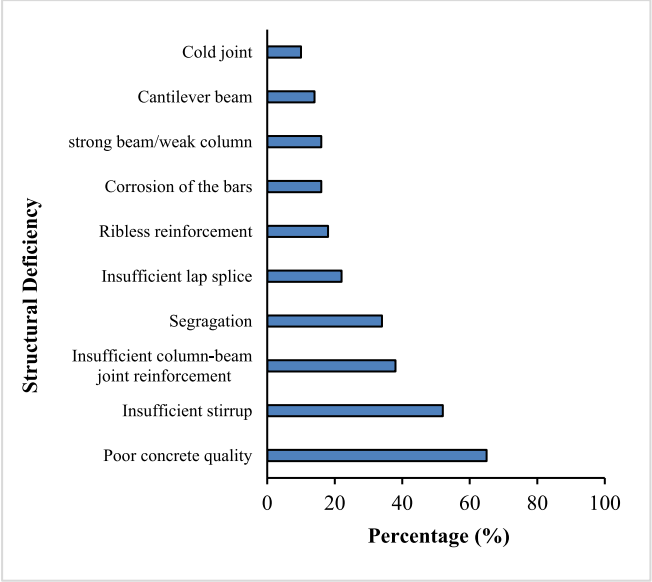


Fig. 24. Percentage of structural deficiency of RC buildings.

should be carried out using sustainable, economical, and practical methods.

- Most of the building stock in the central districts of Malatya was designed in accordance with TEC [18]; TEC [15], and TBEC [16]. Considering that most of the collapsed buildings were not constructed according to TEC [15], and TBEC [16] codes, it is of great importance to rapidly assessment of all reinforced concrete building stock built before 2007 in order to prevent loss of life and property in possible earthquakes throughout the country.
- The material-workmanship deficiencies found in the reinforced concrete buildings that were built during the past five years among the evaluated structures suggest that the building inspection system needs to be revised.
- Aftershocks that occur after major earthquakes also pose a risk. The most recent example of this situation is the occurrence of two major earthquakes with magnitudes $M_w = 7.7$ and $M_w = 7.6$ on February 6, 2024, at 04:17 and 13:24, approximately 9 h apart. Some of the buildings that were heavily damaged in the first earthquake collapsed in the second earthquake, causing casualties. Especially in regions with high population density, earthquake risk analyzes should be made and earthquake-resistant assembly areas with independent communication infrastructure systems should be built to provide solutions to the sheltering needs of citizens in possible earthquakes. In the assembly areas to be designated and should be given both psychological support and information about active risk situations to people.

CRediT authorship contribution statement

Ahmet Ihsan Turan: Data curation, Investigation, Writing – original draft, Writing – review & editing. **Alper Celik:** Investigation, Software, Visualization, Writing – original draft, Writing – review & editing. **Atila Kumbasaroglu:** Investigation, Supervision, Writing – original draft, Writing – review & editing. **Hakan Yalciner:** Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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